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Nutritional Composition and Pesticide Residue Risk in Jujube Fruit: A Comprehensive Review of Benefits and Safety Concerns

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ABSTRACT

Jujube (Ziziphus jujuba) possesses a notable historical significance in the realm of traditional medicine, particularly within the context of Chinese therapeutic methodologies, where it is esteemed for its multifaceted health benefits. Jujubum (Z. mauritiana L.) serves as a vital nutritional food source characterized by an extensive nutritional composition, demonstrating heightened levels of carbohydrates and proteins across various cultivars, thereby affirming its importance as a nutritious aliment. The current review is aimed at investigating the nutritional composition and health advantages associated with jujube, alongside the potential hazards related to pesticide residues found in the fruit. Findings suggest that most pesticide residues are within acceptable limits; however, ongoing monitoring and improved processing methods are vital for consumer health protection. Despite these results, the overall health risks associated with fruit consumption seem manageable, yet cumulative pesticide exposure risks necessitate enhanced agricultural practices and robust regulatory measures. Moreover, while most detected pesticides in the fruit are within acceptable levels, continuous monitoring and the implementation of strict oversight are essential for consumer safety, with an emphasis on educating consumers about its nutritional advantages. Research into jujube's chemical composition and pesticide residue presence indicates significant deficiencies, particularly the absence of long-term studies examining changes over time. Consequently, this review is dedicated to exploring jujube's nutritional composition and health benefits, alongside pesticide residue risks, providing valuable insights for producers, processors, and consumers.

Keywords: *jujube, nutrients, health benefit, pesticide residue, risk*

Introduction

Jujube, a member of the Rhamnaceae family, is extensively cultivated in tropical and subtropical regions, particularly in East Asia, North Africa, and the Middle East. The primary varieties encompass Jujube (*Ziziphus jujube* Mill.), commonly known as Chinese date, which is predominantly located in East Asia, especially in China, where it has been cultivated for over 4,000 years and accounts for nearly 98% of global production. Additionally, the Indian jujube (*Ziziphus mauritiana* Lamk) is also cultivated in tropical and subtropical climates, with notable production in India [3]. China stands as the foremost region for jujube production, contributing over 90% to global jujube cultivation, with approximately 700 recognized cultivars, particularly in provinces such as Xinjiang Shandong and Hebei [5,18] Other species, such as *Ziziphus lotus*, are cultivated in certain Middle Eastern countries [26]. Furthermore, jujube is also cultivated in diverse locations including South Korea, Iran, North Africa, Israel, the United States, and the broader Middle Eastern region [9].

Jujube fruit, particularly the species *Ziziphus mauritiana* and *Ziziphus jujuba*, is widely recognized for its comprehensive nutritional composition, encompassing significant quantities of carbohydrates, proteins, dietary fiber, vitamins, and minerals. The fruit comprises approximately 81.6-83.0% moisture, 17.0% carbohydrates, and 0.8% protein per 100g, exhibiting an exceedingly low-fat content of around 0.07% [22,9]. Notably, jujube serves as an excellent source of vitamin C, with concentrations ranging from 65.8 to 165mg per 100g [18]. It additionally provides essential minerals such as calcium, phosphorus, and iron, which contribute to its health-promoting properties. The bioactive compounds present in the fruit, including polysaccharides and phenolics, further enhance its nutritional significance [25]. Furthermore, jujube fruits contain various amino acids, with certain cultivars exhibiting a high ratio of essential to non-essential amino acids, indicating their potential health benefits [40].

Due to its many health benefits, jujube (*Ziziphus jujuba*) has a long history in traditional medicine, particularly in Chinese customs. The fruit can help with conditions including inflammation, persistent constipation, and newborn jaundice because of its well-known anti-inflammatory, antioxidant, and immune-boosting properties [25,40]. Flavonoids, phenolic acids, and polysaccharides are among the many bioactive compounds found in the peel and pulp of the jujube plant, which contribute to its ability to heal and prevent disease [25]. Additionally, jujube is used in traditional recipes to improve sleep quality, lower anxiety, and improve general well-being [18,5]. Its historical significance and ongoing application underscore its importance in food and health practices. The fruit's health-promoting properties are supported by a wealth of bioactive substances, such as flavonoids, phenolic acids, and polysaccharides. Jujube's fiber content has also been shown to help control blood sugar levels and strengthen the immune system. Jujube is a great functional food since its extracts have been studied for their ability to prevent liver damage and to improve overall health [9].

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Pesticides are widely used in jujube farming because the fruit is vulnerable to many pests and diseases, which requires the use of several pesticides during its growth. Research shows that many jujube samples have pesticide residues, with findings indicating that 70.8% of samples tested positive, and 25% surpassed the maximum residue limits (MRLs) established by China, with even more samples exceeding EU MRLs, creating export risks [35]. Common pesticides like chlorpyrifos and imidacloprid are used to fend off insect problems [29]. The longevity of these residues can be influenced by different factors, such as processing techniques, which can greatly lower pesticide amounts in jujube products [23]. Thus, although jujubes provide considerable nutritional benefits, careful oversight of pesticide use and residue levels is crucial to lessen health risks linked to their consumption [25]. In view of this the present review is focused on the nutritional composition and health benefits of jujube along with the risk of pesticide residue in jujube fruit. Therefore, this review could be a useful piece of work for jujube producers, jujube processing units and consumers.

2. Nutritionalcomponents

2.1 Macronutrients

Jujube fruits are acknowledged for their abundant macronutrient composition, encompassing considerable quantities of proteins, carbohydrates, fats and dietary fiber.

Protein and amino acid: The jujube fruit is esteemed for its significant nutritional properties, notably its protein composition, which exhibits variability between its fresh and dehydrated states. Fresh jujube fruit contains an estimated 1.2g of protein per 100g, whereas the dehydrated variant demonstrates a considerably elevated protein concentration of approximately 4.72g per 100g [34]. The jujube fruit is characterized by a diverse array of amino acids, with research identifying a total of fourteen distinct types, encompassing essential amino acids such as threonine, valine, leucine, phenylalanine, and isoleucine, in addition to non-essential amino acids including glycine, proline, and alanine. The cumulative amino acid concentration across 161 jujube cultivars averaged 1.28 g/100 g, with proline being the predominant amino acid at 0.727 g/100 g, and the highest concentration recorded in the cultivar 'Zaoqiangmalianzao' at 2.356 g/100 g [39]. Furthermore, a study identified a total of 18 amino acids in four specific jujube cultivars (“Hupingzao,” “Huizao,” “Xiaozao,” and “Junzao”) cultivated in the northwestern region of China. Proline (Pro), aspartic acid (Asp), and glutamic acid (Glu) were found to constitute 64.5% to 70.0% of the overall amino acid profile [12].

Carbohydrate: Jujube fruits exhibit a high concentration of diverse carbohydrates, predominantly comprising sugars such as sucrose, glucose, fructose, rhamnose, and mannose. The carbohydrate composition demonstrates considerable variation across different stages of maturity, with sucrose emerging as the most abundant sugar, succeeded by mannose, galactose, fructose, and glucose, all of which increase in concentration as the fruit undergoes ripening [39]. Research suggests that the carbohydrate content within jujube can fluctuate between 80.86% and 85.63%, with reducing sugars representing a significant fraction of this composition [15]. Furthermore, the quantification of soluble sugars in jujube fruits is documented to be approximately 10 g per 100 mL when in juice form, underscoring their nutritional significance [5].

The total soluble solid (TSS) concentration in jujube fruits is subject to variation across different cultivars and research studies. For example, one investigation noted TSS values ranging from 8.1 to 18.4 degrees Brix in Spanish jujubes, signifying marked variability influenced by cultivar selection and environmental conditions [6].

Fat and fiber: The jujube fruit is characterized by a minimal fat content, which typically fluctuates between 0.2% and 1.02%, contingent upon the specific cultivar and the processing techniques employed [26,22]. Regarding dietary fiber, jujube encompasses both soluble and insoluble fractions, with the soluble fiber content documented to range from 0.57% to 2.79%, while the insoluble fiber is reported to vary between 5.24% and 7.18% [15].

2.2 Micronutrient

Jujube fruits are esteemed for their abundant micronutrient composition, encompassing essential vitamins and minerals. They exhibit particularly elevated levels of vitamin C, along with being a commendable source of minerals such as potassium, calcium, phosphorus, and iron, all of which are indispensable for diverse physiological functions. The fruit further encompasses trace elements including zinc, manganese, and copper, thereby augmenting its comprehensive nutritional profile [26].

Vitamins: Jujube fruits are recognized for their high vitamin content, particularly vitamin C, which ranges from 70 to 363mg per 100g depending on the cultivar and ripeness [22]. Additionally, jujubes provide other essential vitamins, including thiamin (0.02-0.08mg/100g), riboflavin (0.04-0.09mg/100g), and niacin, contributing to their nutritional value. The presence of these vitamins supports various health benefits, including cardiovascular health and metabolism enhancement. Furthermore, jujube fruits contain bioactive compounds such as phenolics, which may also contribute to their overall health-promoting properties [9,26,5].

Minerals: The fruits of the jujube are acknowledged for their considerable calcium concentration, which exhibits variability across distinct cultivars. For example, the calcium concentrations in Chinese jujube cultivars fluctuate between 45.6 and 118mg per 100g, with certain research suggesting a potential role of calcium in the reduction of blood pressure [15]. In the case of Indian jujube (*Ziziphus mauritiana*), the calcium concentration is estimated at approximately 0.03% [8]. In a comparative analysis of five Chinese jujube cultivars, potassium concentrations were observed to range from 79.2 to 458mg per 100g, with *Ziziphus jujuba* cv Yazao exhibiting the highest concentration [15]. Furthermore, an additional investigation revealed that jujube fruit encompasses roughly 899.82mg of potassium per 100g [13]. Jujube fruits are distinguished for their mineral composition, which includes phosphorus, iron, zinc, copper, manganese, and sodium. In the context of Chinese jujube, phosphorus concentrations can attain levels as high as 110mg per 100g, whereas iron content demonstrates variability, ranging from 4.68 to 7.90mg per 100g among various cultivars. Zinc and copper are also present, with zinc concentrations approximating 0.35 to 0.63mg per 100g and copper concentrations fluctuating between 0.19 and 0.42mg per 100g. Manganese content is also noteworthy, presenting values ranging from 24.6 to 51.2mg per 100g. Sodium concentrations in jujube exhibit variability, with the highest recorded level being 7.61mg per 100g [15].

3. Health benefits related to nutritional components

Anti-oxidant: The jujube fruit demonstrates pronounced antioxidant properties, which can be ascribed to its elevated concentration of phenolic compounds and flavonoids. Research has indicated that various cultivars of jujube, including *Zizyphus jujuba* cv. jinsixiaozao, exhibits disparate levels of antioxidant efficacy, with certain extracts exceeding the performance of α-tocopherol in DPPH radical scavenging and reducing power evaluations [14]. The fruit's capacity to augment the functionality of antioxidant enzymes, such as superoxide dismutase (SOD) and glutathione (GSH), further corroborates its significance in alleviating oxidative stress [19]. Moreover, the existence of phytochemical constituents, including tannins and saponins, within jujube extracts enhances their antioxidant properties, thereby positioning them as promising candidates for therapeutic interventions aimed at combating oxidative damage [9].

Anti-allergic: Recent investigations have underscored the anti-allergic properties of natural compounds sourced from *Ziziphus* species. The Most Active Fraction (MAF) derived from *Z. mauritiana* demonstrates considerable inhibition of the complement system as well as enzymes implicated in allergic reactions, such as COX-1, COX-2, and 5-LOX, exhibiting a particularly pronounced effect on COX-2, which is advantageous in mitigating the risk of gastric injuries linked to non-selective COX inhibitors [31]. Moreover, the immune regulatory capabilities of jujube extracts, particularly their potential to enhance immune responses, indicate prospective applications in the management of allergies and inflammation [19].

Anti-carcinogenic: In numerous scientific studies, *Ziziphus jujuba* and *Ziziphus mauritiana* have demonstrated significant anticancer benefits. In human hepatoma (HepG2) and breast cancer cell lines (MCF-7 and SKBR3), extracts from *Z. jujuba* have been shown to induce apoptosis, mainly employing processes involving the increase of reactive oxygen species and the cell cycle arrest [7]. Additionally, in in vivo investigations, *Z. mauritiana* seed extracts showed a dose-dependent suppression of HL-60 leukemia cells and reduced tumor volume, indicating its potential use as an anticancer therapeutic agent [20]. Furthermore, in animal model systems, jujube fruit consumption has been linked to a lower incidence of colon cancer, which is explained by the suppression of particular signaling pathways [24]. The remarkable potential of jujube extracts in the fields of cancer prevention and therapeutic intervention is highlighted by these combined findings.

Anti-diabetic: Numerous studies have confirmed *Ziziphus mauritiana*'s antidiabetic qualities, showing significant reductions in high blood glucose levels and other biochemical markers in diabetic animal models. In alloxan-induced diabetic rodent models, aqueous extracts from *Z. mauritiana* fruits and seeds significantly reduced blood glucose levels; the non-polysaccharide component of the aqueous extract showed the strongest effect. Additionally, when given with glyburide, the extracts improved glucose tolerance and showed synergistic effects [1]. Similar antihyperglycemic effects were shown by other species, such as *Ziziphus oenoplia* and *Ziziphus lotus*, which helped lower serum glucose and lipid profiles. These effects were likely caused by the flavonoid components in these species [21].
These collective findings underscore the potential of *Ziziphus* species as viable natural agents for diabetes management.

Other Health benefits: Jujube-derived dietary products demonstrate considerable cardio-protective properties, particularly through the suppression of foam cell formation triggered by acetylated low-density lipoprotein (LDL), which is a pivotal factor in atherosclerosis pathogenesis. Notable bioactive constituents, such as triterpenoids including oleanonic acid, pomolic acid, and pomonic acid, have been recognized for their efficacy in diminishing foam cell formation in human macrophages [4]. The hepatoprotective properties of *Ziziphus mauritiana* and jujube fruit have been substantiated in a variety of scholarly investigations. In experimental models involving rats, the aqueous leaf extract of *Z. mauritiana* exhibited a significant reduction in liver enzyme levels (ALT, ALP, AST) and an enhancement in antioxidant enzyme activity, indicating a protective effect against alcohol-induced hepatic injury, presumably attributable to its phytochemical constituents such as tannins and saponins [9]. In a similar vein, jujube fruit demonstrated protective effects against carbon tetrachloride (CCl_4)-induced hepatic injury in murine models, as evidenced by diminished serum liver enzyme levels and improved antioxidant profiles [5]. The ethanolic extract of *Z. mauritiana* L. leaves reveals pronounced wound-healing capabilities, as evidenced by empirical studies conducted on Wistar albino rats utilizing excision, incision, and dead space wound models. Administration over a duration of ten days led to accelerated wound contraction, a reduction in epithelization duration, and an enhancement in skin-breaking strength. Furthermore, the extract augmented the weight of dry granulation tissue and elevated hydroxyproline levels, signifying enhanced collagen deposition within the wound milieu. Collectively, these findings indicate that the ethanolic extract not only facilitates wound closure but also promotes tissue regeneration and collagen synthesis, underscoring its potential therapeutic implications in the realm of wound healing [30].

4. Pesticide residues risk in jujube fruit

The application of pesticides in the cultivation of jujube is widespread due to the fruit's vulnerability to an array of pests and diseases, necessitating recurrent treatments throughout the growth cycle, which typically spans approximately nine months [39]. Research findings reveal that a considerable proportion of jujube samples exhibit pesticide residues, with a subset surpassing the maximum residue limits (MRLs) established by regulatory authorities, particularly within the European Union [37]. Evidence suggests that the pesticide difenoconazole demonstrates a prolonged half-life in jujube compared to other crops, a phenomenon that may be ascribed to specific environmental factors and the developmental stage of the fruit at the time of application [29].
The array of pesticides commonly utilized in jujube cultivation encompasses dichlorvos, malathion, chlorpyrifos, triadimefon, hexaconazole, myclobutanil, kresoxim-methyl, tebuconazole, epoxiconazole, bifenthrin, cyhalothrin, chlorothalonil, glyphosate, imidacloprid, pyraclostrobin, azoxystrobin, and fipronil, which are frequently administered at intervals of 7 to 10 days to effectively control pest populations and maintain the integrity of crop quality [39,37,2,23,27].
Pesticide residues in jujube have emerged as a critical issue, with empirical research suggesting that a considerable proportion of samples exhibit residues that exceed the established maximum residue limits (MRLs). It is documented that 70.8% of jujube samples were found to contain pesticide residues, with 25.0% surpassing the MRLs set by China and

62.5% exceeding the more stringent MRLs enforced by the European Union, thereby posing potential risks to export markets [17]. Eleven distinct pesticide residues were identified in jujube, with degradation rates observed during drying processes ranging between 11.4% and 95.1%, which consequently influences dietary exposure risks contingent upon the drying methodologies employed [37]. Residues of chlorpyrifos, hexaconazole, tebuconazole, and cyhalothrin were detected in jujube samples available in the marketplace, thereby underscoring apprehensions regarding the improper application of pesticides in this relatively minor agricultural crop [39]. Residue levels of difenoconazole in jujube were quantified as ranging from 0.11-1.59mg/kg at 7 days, 0.05-0.77 mg/kg at 14 days, and 0.04-0.63mg/kg at 21 days after application [29]. A research investigation revealed the presence of pesticide residues such as chlorothalonil, malathion, and glyphosate in jujube fruit, with melatonin treatment demonstrating a statistically significant reduction in these residues following storage [2]. Carbendazim residues were detected in jujube foliage for 14 days' post-treatment, whereas harpin, characterized as an environmentally benign biopesticide, exhibited no deleterious residues, thereby enhancing leaf quality without adverse effects [33].

A multitude of methodologies for the detection of pesticide residues has been formulated, underscoring the importance of efficiency and precision. Gas chromatography (GC) is utilized for the analysis of a diverse array of compounds, employing various configurations and detectors. For example, an Agilent 6890 N Network GC system, integrated with a mass spectrometer (GC-MS), was employed for pesticide detection, utilizing the selected ion monitoring mode alongside a specialized capillary column and helium as the carrier gas [37]. Moreover, an alternative configuration incorporated GC with an electron capture detector (GC-ECD), which utilized a DB-1701 capillary column and nitrogen as the carrier gas, thereby illustrating the adaptability of GC in the detection of organochlorines and other chemical entities. The operational parameters, including injector and oven temperatures, are pivotal for the enhancement of analyte separation and detection [17]. These methodologies exemplify the efficacy of gas chromatography in the realms of environmental and pesticide analysis. It stands as a prominent analytical technique, employed for the examination of pesticide residues in jujube fruits, achieving limits of detection (LOD) as low as 0.001 mg/kg for a range of pesticides [25].

The levels of pesticide residues in agricultural products are influenced by environmental factors, application methods, pesticide properties, drying techniques, and food processing. Residue levels depend on soil contamination and vary with pesticide type and environmental conditions [17]. Application methods significantly impact residues, with processes like peeling reducing levels of pesticides such as imidacloprid and azoxystrobin [23]. Physicochemical properties also play a role; organophosphates degrade more easily during drying, while pyrethroids persist due to lower volatility [37]. Drying methods can amplify or reduce residues, as seen in the increased phosalone in oven-dried raisins or decreased residues in dried chili peppers [37]. Processing further alters residue levels, with reductions or concentration effects depending on the pesticide, such as triadimefon decreasing during fermentation while triadimenol concentrates [23].

The health hazards associated with pesticide residues in jujube (*Ziziphus jujuba*) primarily stem from the presence of various pesticides, including organophosphates, organochlorines, and pyrethroids. While some studies suggest that the cumulative health risk from consuming jujube is minimal, certain pesticide residues can exceed established safety thresholds. A study found that 70.8% of jujube samples tested positive for pesticide residues, with concentrations ranging from 1.0µg/kg to 2945.0µg/kg, and many samples exceeding the maximum residue limits (MRLs) set by China. The most commonly detected pesticides were cypermethrin and triadimefon [17,38]. Risk assessments identified aldrin and dieldrin as the most concerning, while difenoconazole posed an acceptable risk, with its residues diminishing over time [27]. Additionally, processing methods such as drying and fermentation can impact pesticide concentrations, sometimes reducing them but potentially converting them into more harmful metabolites [38,37]. Despite these risks, the overall health threat from consuming jujube remains manageable, though continuous monitoring and improved agricultural practices are crucial to mitigate potential dangers.

Cutting-edge analytical techniques and integrated surveillance systems are becoming more and more important in emerging trends and technology developments in pesticide risk assessment and food safety. These developments seek to improve risk assessment procedures and improve the detection of pesticide residues. The application of microfluidic devices, which have become well-known for their capacity to combine several analytical procedures onto a single microchip, is one noteworthy development. The quick and accurate identification of pesticide residues in food is made possible by this capability [10]. Additionally, the detection sensitivity has been greatly enhanced by integrating microfluidics with nanomaterials and 3D printing technology, which qualifies it for in-situ applications [10]. Ambient ionization mass spectrometry (AIMS), which allows for the direct, real-time analysis of pesticide residues, is another noteworthy technological advancement. This method positions itself as a promising tool for food safety evaluations by doing away with the necessity for intricate sample preparation [16]. Accurate risk assessments also depend on integrated risk assessment techniques, which integrate data from food and human biomonitoring. This integration can result in large decreases in consumer exposure, as evidenced by research on chlorpyrifos [32]. Together, these developments make food safety monitoring and pesticide risk assessment more precise and efficient.

Summary: The jujube fruit is acknowledged for its extensive nutritional composition, exhibiting elevated proportions of carbohydrates and proteins across diverse cultivars, thereby establishing its significance as a nutritional food source. Furthermore, jujubes are distinguished by their array of bioactive compounds, inclusive of various vitamins and minerals, which enhance their health-promoting properties. Nevertheless, apprehensions regarding the presence of pesticide residues remain, as research reveals that a notable fraction of jujube samples contains residues that surpass the established maximum residue limits (MRLs), particularly concerning the regulations set forth by the European Union. The dehydration process further influences pesticide residue levels, with desiccated jujubes exhibiting disparate concentrations of residues contingent upon the employed drying methodology. In conclusion, while jujubes offer substantial nutritional advantages, the oversight of pesticide residue levels is imperative for the assurance of food safety.

Future scope of the study: Research on the chemical makeup of jujube and the presence of pesticide residues reveals significant gaps, including the lack of long-term studies that look at changes in composition and residues over time. Research that clarifies the effects of different processing techniques on nutritional value and residue levels is also desperately needed. Additionally, little research has been done on consumer behavior in terms of jujube purchasing patterns and awareness of pesticide implications, and there are substantial gaps in our understanding of the interactions between bioactive compounds and pesticide residues. Future studies that address these shortcomings could greatly advance our knowledge of the safety and nutritional worth of jujube, which would benefit producers, consumers, and legislators alike.

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